

The Impact of Temporal Decorrelation over Forest Terrain in Polarimetric SAR Interferometry

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ABSTRACT

While polarimetric SAR interferometry (Pol-InSAR) techniques are today well established, a critical issue in the case of repeat-pass spaceborne measurements is temporal decorrelation, caused by changes within the scene occurring in the time between the acquisitions. Indeed, temporal decorrelation has been identified as the most critical factor for a successful implementation of Pol-InSAR parameter inversion techniques in terms of conventional space-borne repeat-pass InSAR scenarios. Similar to any other system induced decorrelation contribution, temporal decorrelation reduces the performance of Pol-InSAR techniques by biasing the volume decorrelation contribution used for parameter inversion. This leads to an increased standard deviation of the InSAR phase - for the same number of looks - and introduces a bias in the parameter estimates. In this paper first we analyze repeat-pass Pol-InSAR data acquired in the frame of dedicated experiments in order to quantify temporal decorrelation for temporal baselines in the order of days up to 4 and 8 weeks at L-band for two different forest types: temperate and boreal forests.

1. INTRODUCTION

Polarimetric Synthetic Aperture Radar Interferometry (Pol-InSAR) is a recently developed radar technique based on the coherent combination of radar polarimetry and SAR interferometry. The potential of Pol-InSAR techniques in forest parameter estimation is based on

the ability to separate volume from surface scattering contributions and to recover the vertical distribution of scatterers in mixed (volume) scattering scenarios [1], [2].

The amount of temporal decorrelation depends on the structure of the scatterers related to the used radar frequency and on the environmental processes occurring in the time during and between the interferometric acquisitions. Temporal changes occur - in general - within the scene in stochastic, spatial and temporal patterns and cannot be modeled with the required accuracy without detailed information about the (environmental) conditions over time between the two observations [3], [4]. While there is a relative good understanding of decorrelation rates for temporal baselines on the order of 30-45 days at C- and L-band provided by the data of the ERS and JERS missions, as well as for baselines on the order of 10-70 min provided by airborne repeat-pass data sets (at C-, L- and P-band) there is poor understanding of the decorrelation levels expected at temporal baselines on the order of hours and days.

In June 2008 DLR's E-SAR (Experimental Airborne SAR) collected fully polarimetric and interferometric SAR data over the temperate forest in Traunstein, Germany to investigate temporal baselines in the order of days and weeks. For this campaign data have been acquired in L- and X-band. E-SAR system carried out three campaigns over Remningstorp forest, Sweden in early March, early April and early May 2007. During these three dates data acquisition at L- and P-band in a repeat pass fully polarimetric mode were performed [4]. Test site and temporal baseline of both campaigns are summarized in Table 1. We further assess the impact of

Table 1. BioSAR 2007 and TempoSAR 2008 campaigns; test site, temporal baseline, forest height, biomass, etc.

Campaign	Date	Temporal baseline	Band	Test site	Forest type	Forest height	Biomass
TempoSAR	2008/06/07 - 2008/06/20	1 – 13 days	L- & X-band	Traunstein (Germany)	Temperate	25 – 30 m	300 t/ha
BioSAR	2007/03/09 - 2007/05/02	30 & 54 days	L- & P-band	Remningstorp (Sweden)	Boreal	25 – 30 m	450 t/ha

the estimated temporal decorrelation levels on the performance of Pol-InSAR inversion techniques. Finally we attempt to describe the estimated temporal decorrelation behavior observed at L-band and use it to draw some conclusions about different acquisition scenarios.

2. POL-INSAR INVERSION & TEMPORAL DECORRELATION

The key observable used in Pol-InSAR application is the complex interferometric coherence $\tilde{\gamma}$ estimated at different polarizations. The estimated coherence depends on instrument and acquisition parameters as well as on dielectric and structural parameters of scatterers. After calibration of system-induced decorrelation in azimuth and range, the estimated coherence can be composed into different decorrelation contributions.

$$\tilde{\gamma} = \tilde{\gamma}_{\text{temporal}} \gamma_{\text{SNR}} \tilde{\gamma}_{\text{volume}} \quad (1)$$

Volume decorrelation $\tilde{\gamma}_{\text{volume}}$ is the decorrelation caused by the different projection of the vertical component of the scatterer into two SAR images. $\tilde{\gamma}_{\text{volume}}$ is directly linked to the vertical distribution of scatterers $F(z)$ through a (normalized) Fourier transformation relationship. A widely and successfully used model for $F(z)$ is the so-called Random Volume over Ground (RVoG), a two-layer model. It is a two-layer model composed by a vegetation layer (canopy + trunks) and a ground component. The vegetation layer is modeled as a layer (volume) of given thickness containing randomly oriented particles characterized by scattering amplitude per unit volume. The random volume is located over an impenetrable ground scatterer characterized by its own scattering amplitude. The volume decorrelation caused by the vegetation layer only can be described as

$$\tilde{\gamma}_{V0} = \exp(i\kappa_z z_0) \frac{\int_0^{h_v} \exp(i\kappa_z z') \exp\left(\frac{2\sigma z'}{\cos\theta_0}\right) dz'}{\int_0^{h_v} \exp\left(\frac{2\sigma z'}{\cos\theta_0}\right) dz'} \quad (2)$$

where h_v is the height of the volume and κ_z the effective vertical (interferometric) wave-number that depends on the imaging geometry and the radar wavelength λ . θ_0 is the incidence angle and σ is a mean

extinction coefficient [1], [2].

Assuming no response from the ground in one polarization channel, the inversion problem has a unique solution and is balanced with five real unknowns ($h_v, \sigma, m_{I-2}, \varphi_0$) and three measured complex coherences $[\tilde{\gamma}(\bar{w}_1) \tilde{\gamma}(\bar{w}_2) \tilde{\gamma}(\bar{w}_3)]$ each for any independent polarization channel

$$\min_{h_v, \sigma, m_i, \varphi_0} \left\| \begin{bmatrix} \tilde{\gamma}(\bar{w}_1) & \tilde{\gamma}(\bar{w}_2) & \tilde{\gamma}(\bar{w}_3) \end{bmatrix}^T - \begin{bmatrix} \tilde{\gamma}_V(h_v, \sigma, m_1) & \tilde{\gamma}_V(h_v, \sigma, m_2) & \tilde{\gamma}_0 \exp(i\varphi_0) \end{bmatrix}^T \right\| \quad (3)$$

However, this RVoG model does not account for decorrelation effects due to dynamic changes within the scene occurring in the time between the two acquisitions. Such changes effecting the location and/or the scattering properties of the effective scatterers within the scene reduce in general the correlation between the acquired images and lead to erroneous and/or biased parameter estimates. In general, temporal decorrelation within the scene occurs in a stochastic manner and cannot be accounted for without detailed information about the environmental conditions over the time between the two observations.

3. EXPERIMENTAL RESULTS

Temporal decorrelation reduces the interferometric coherence and increases the variation of interferometric phase and biases forest height estimates. In order to provide some insights in the nature of different temporal decorrelation mechanisms over forest areas at L-band E-SAR airborne experiments will be discussed in the following. The first one is a very long term repeat pass experiment (more than 30 days) over Remningstorp forest in Sweden while the second one is experiment over Traunstein forest with smaller than 2 weeks temporal baselines. Inversion height results of both forests are shown in figure 2. The interest is primarily in evaluating the levels of coherence loss due to temporal changes occurring in the time between the passes. And we attempt to estimate height error in different temporal baselines. With these results, temporal decorrelation will be decomposed from interferometric coherence.

Longer than one month temporal baseline:

BioSAR campaign has 0, 30 and 54 days temporal baselines. Effects of temporal decorrelation are shown in figure 1, here coherence histograms of HH, VV, and HV polarizations over the whole scene for three temporal baselines (all acquired with 0m nominal spatial baseline) are plotted. As expected, temporal

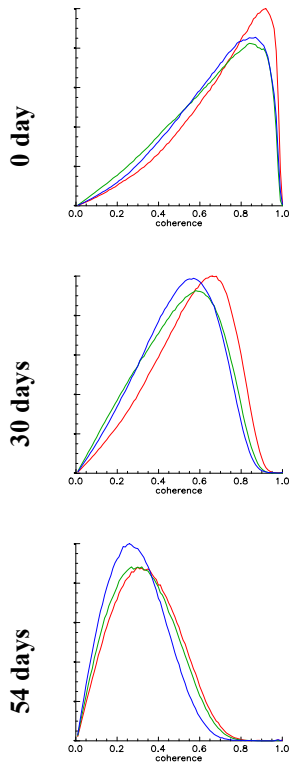


Figure 1. Coherence histograms of 0, 30, 54 days temporal baselines; HH(red), HV(green), and VV(blue)

decorrelation decreases with time independent from polarizations. Even in the 0 day scenario some decorrelation effects can be observed.

Also here the data are acquired in a repeat pass mode with temporal baselines in the order of one hour. However, in an airborne scenario 0 m baseline is difficult to fly as there are always some deviations in the baseline (flight track). Deviations from the nominal baseline (0 to 3 m) cause volume decorrelation which drops coherence over forested areas [4]. As seen in figure 1 temporal decorrelation reduces coherence level to 0.65 (30 days) and 0.3 (54 days). Coherence with 54 days temporal baseline is too low to apply valuable Pol-InSAR application. Forest height was estimated with one month temporal baseline, shown in figure 3. Inversion forest height is fairly overestimated all over the image due to the temporal decorrelation. Difference height between inversion height and overestimated forest height is shown on the right in figure 3. The level of temporal decorrelation with 30 days repeat-pass cycle of L-band makes a height inversion still feasible, but introduces a big height bias.

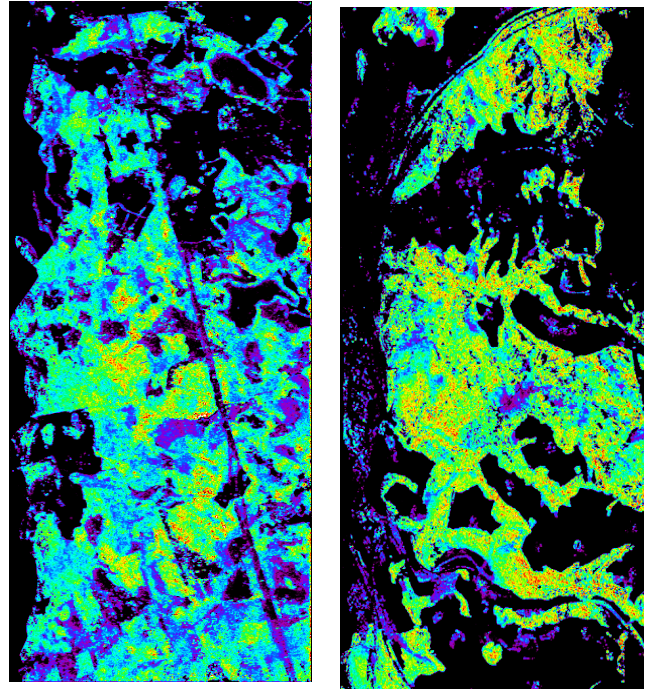


Figure 2. Forest height maps for Remningstorp forest (left), and Traunstein forest (right), scaled from 0 to 50 m.

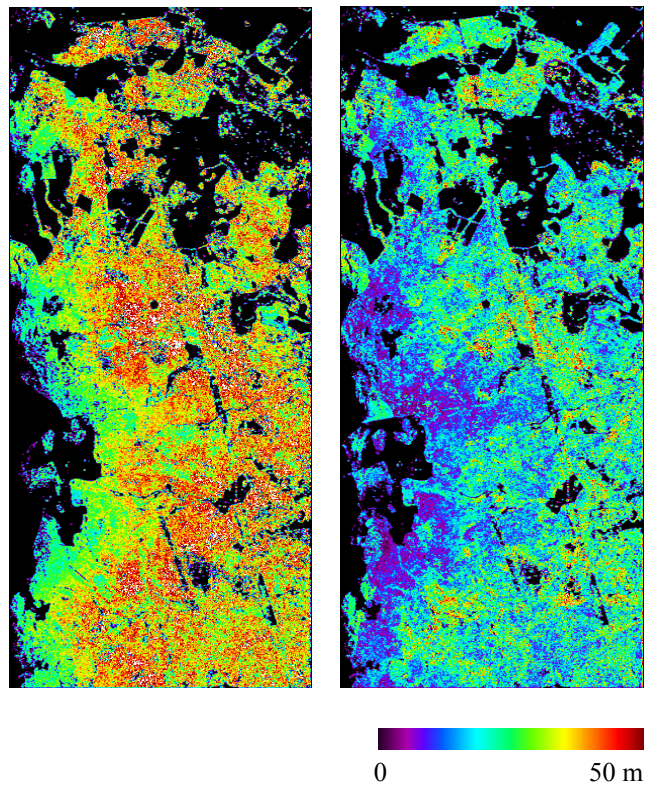


Figure 3. Forest height maps for Remningstorp forest, scaled from 0 to 50 m, Inversion height map with 1 month temporal decorrelation (left), Difference height map (Right)

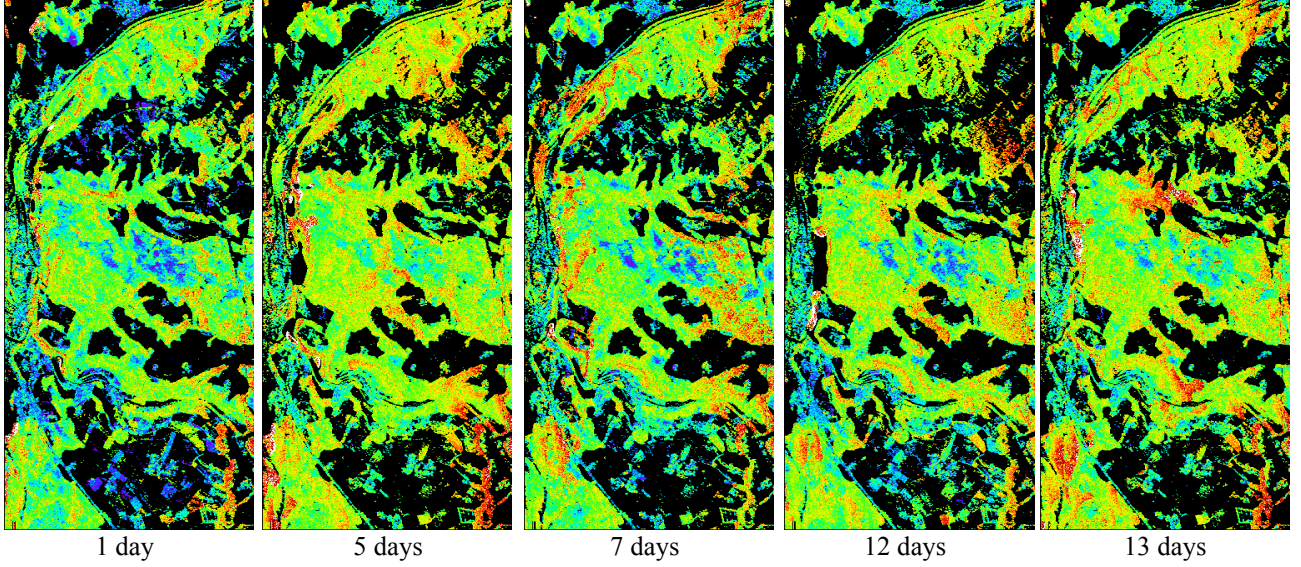


Figure 4. Forest height maps with temporal baselines, from 1 day to 13 days.

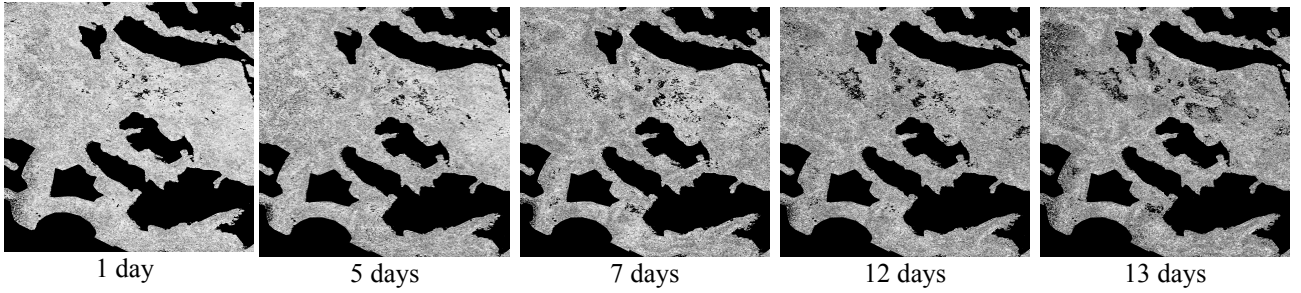


Figure 5. Temporal decorrelation (Γ_{temporal}) from 1 day to 13 days, scaled 0 to 50m

Shorter than 13 days temporal baseline:

TempoSAR campaign has six acquisition dates so that can be able to generate several temporal baselines from 1 day to 13 days. Figure 4 shows forest heights with these temporal baselines from 1 day to 13 days. As expected, overestimation tends to increase in time series (comparing to figure 2, right). Height errors in temporal baselines were estimated as

$$\text{Height error (\%)} = \frac{\Delta H}{\text{Height}} \times 100 \quad (4)$$

where ΔH is overestimated height and *Height* means forest height without day order temporal baselines.

Height error is the tendency of increasing with decrease forest height (see on the left in figure 6). This is related to Pol-InSAR model. Low forest is more affected by uncompensated decorrelation effects in inversion model [3]. Color shows temporal baselines. Even 1 day temporal decorrelation leads to 20-100% overestimation

depending on forest height. L-band inversion results are affected by rather stochastic temporal effects due to the variable wind induced motions.

With temporal baseline forest is always overestimated because temporal decorrelation decorrelates volume coherence. We attempt to investigate the relation between overestimated height and temporal decorrelation. By using the information of height error in time, we can calculate how much forests are overestimated and correct inversion forest height. Volume coherence can be estimated by corrected forest height and equation (2) on the assumption that extinction does not change between the acquired images. Temporal decorrelation will be simply estimated interferometric coherence divided by volume decorrelation, see equation (1). The estimated temporal decorrelations are shown in figure 5. Here we can see two points; First one is that temporal decorrelation tends to decrease as temporal baseline increases. The other is that temporal decorrelation is not one constant value in

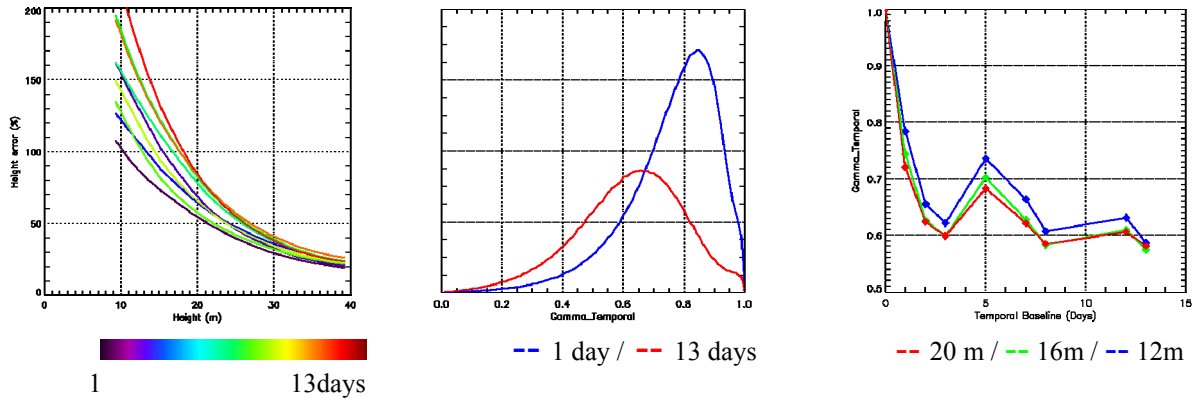


Figure 6. Height error with temporal baselines (left), Histograms of temporal decorrelation (γ_{temporal}) for 1 day (blue) and 13 days (red) temporal baselines (middle), γ_{temporal} against temporal baselines, red means 20 m forest, green 16 m, blue 12 m (right).

time. It depends on forest height and the inconsistent wind induced motion.

The histograms of 1 day and 13 days temporal decorrelation are shown on the middle in figure 6. The average of $\tilde{\gamma}_{\text{temporal}}$ is about 0.75 for 1 day (blue) and 0.59 for 13 days (red) temporal baseline.

Right plot in figure 6 shows the estimated temporal decorrelation against temporal baselines. If there is no temporal decorrelation, for example, single pass system, γ_{temporal} should be 1. γ_{temporal} tends to decrease with increasing temporal baseline. Temporal decorrelation drops rapidly but, it does not drop to insignificant coherence level (<0.3) within few day temporal baseline. In this case, the most common temporal decorrelation effect comes from the wind-induced movement of unstable scatterers within canopy layer, for example, leaves or branches. But, if temporal baseline increases more, volume coherence is more decorrelated by not only the wind induced motions but also other events, for example, ground condition changes, water content, breaking branches, falling, etc. After all coherence level becomes too low to allow any quantitative evaluation and/or analysis.

4. CONCLUSIONS

For this study a required amount of Pol-InSAR data were available in L-band in various temporal baselines. Temporal decorrelation is always present for repeat-pass time interval and introduces a height bias.

The level of temporal decorrelation with 54 days repeat-pass time of L-band BioSAR data makes Pol-InSAR application not possible. In case of 30 days temporal baselines, Pol-InSAR height inversion was still feasible but forest height was quite overestimated due to the uncompensated temporal decorrelation. More

than one month temporal decorrelation at L-band is too large to allow quantitative evaluation and analysis.

In this study we attempt to estimate two points with smaller than 2 weeks temporal baselines: One is the height error induced by temporal decorrelation. Height error tends to decrease with increase forest height. Note that only 1 day temporal decorrelation causes up to 20 - 100% height error. As temporal baseline increases, height error was affected by rather stochastic (wind induced) temporal decorrelation effects. The other is that temporal decorrelation was separated from another distributions of observed interferometric coherence. Temporal decorrelation decreases 0.75 to 0.59 with increase temporal baseline from 1 to 13 days. At first temporal decorrelation drops rapidly by mainly wind induced movement of unstable scatterers within canopy layer and subsequently decreases steadily by additional changes of relatively stable scatterers, for example, ground, truck, etc.

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